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SUPERSONIC AERODYNAMIC CHARACTERISTICS OF A 1/6-SCALE MODEL OF THE FINAL TWO STAGES OF THE ARGO D-4 FOUR-STAGE ROCKET VEHICLE

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SUMMARY

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An investigation has been made to determine the aerodynamic characteristics of a 1/6-scale model of the final two stages of the Argo D-4 rocket vehicle. Three sets of cruciform fins were investigated on the model. Two sets were trapezoidal in planform, had a flat double-wedge airfoil section, and differed only in size. The third set had an area equal to that of the larger trapezoidal fins, but had swept leading and trailing edges and a single-wedge airfoil section. All the fin configurations were tested with the fins canted 1.1° to provide positive roll. In addition, the small trapezoidal fins were tested with the fins uncanted and also in a 45° roll attitude. The investigation was conducted at Mach numbers from 2.30 to 4.63 at a Reynolds number per foot (per 0.3048 m) of 3.0×10^{6}.

The results of the investigation indicated that the swept-fin configuration provided greater longitudinal stability than the trapezoidal-fin configuration of equal area because of a greater effective moment arm and a generally increased lift-curve slope. The swept-fin configuration also provided a greater rolling moment than the trapezoidal-fin configuration of equal area. There was no appreciable effect of small-trapezoidal-fin roll attitude on either longitudinal stability or rolling moment. Cant angle of the small trapezoidal fins had little effect on the longitudinal stability of the model.

Author

INTRODUCTION

The Argo D-4 is a four-stage rocket vehicle, consisting of the Honest John M6 as first stage, the Nike-Ajax M5 booster as second stage and third stage, and the Altair I-A6 as fourth stage, for use in a number of space research projects. The accurate determination of its third- and fourth-stage stability characteristics is desirable in order to permit the use of payloads of different weights, the refinement of dispersion predictions, and the evaluation of the effect of third- and fourth-stage deviation from normal flight path. Efforts have been made to determine the stability characteristics of the third and fourth stages analytically, but because of the diameter change between the two stages (the fourth stage being larger in diameter than the third stage) it is difficult to determine accurately the lift coefficient and center of pressure of these two stages. A wind-tunnel program was therefore initiated to determine experimentally the aerodynamic characteristics of a 1/6-scale model of the third and fourth stages of the Argo D-4 vehicle. The Mach number range of the investigation was from 2.30 to 4.63, which was the approximate Mach number range of the third-stage flight.

The fourth stage, or forebody, had an ogive nose and was approximately 17 percent larger in diameter than the third stage, and its length was about 47 percent of the combined third- and fourth-stage length. The fineness ratio of the combined configuration based on the third stage was about 17.4. The two stages were joined by a boattail fairing.

The model consisted of the third- and fourth-stage combination and was investigated with three different sets of cruciform fins attached to the afterbody near the base. One set was trapezoidal in planform and had a slab section with wedge-shaped leading and trailing edges. Another set was similar but of increased size. The third set was equal in area to the second set but had swept leading and trailing edges. This last set also had a wedge airfoil section. All the canted fins had a 1.1° cant angle to provide a positive rolling moment. The model was also tested with the small trapezoidal canted fins in a 45° roll angle and also with the small trapezoidal fins uncanted.

The investigation was conducted in the Langley Unitary Plan wind tunnel at Mach numbers from 2.30 to 4.63 at angles of attack from -4° to 13° with an angle of sideslip of 0°. The Reynolds number per foot (per 0.3048 m) was maintained at 3.0×10^{6}.

SYMBOLS

The force and moment data are presented in coefficient form referred to the body axis system with the moment reference center located on the model center line at a point 61.8 percent of the model length aft of the model nose. Measurements for this investigation were taken in the U.S. Customary Units but are also given parenthetically in the International System of Units.

A_e exposed aspect ratio, determined for exposed span and planform area

C_A axial-force coefficient, $\frac{\text{Axial force}}{qS}$

C_m pitching-moment coefficient, $\frac{\text{Pitching moment}}{qSd}$

C_N normal-force coefficient, $\frac{\text{Normal force}}{qS}$

C_l rolling-moment coefficient, $\frac{\text{Rolling moment}}{qSd}$

C_{m_α} stability parameter at $\alpha = 0^\circ$, $\frac{\partial C_m}{\partial \alpha}$, per deg

C_{N_α} normal-force effectiveness parameter at $\alpha = 0^\circ$, $\frac{\partial C_N}{\partial \alpha}$, per deg

l length of model, third- and fourth-stage combination

d third-stage base diameter, 2.74 in. (6.960 cm)

M Mach number

q free-stream dynamic pressure, lbf/ft^2 (N/m^2)

S third-stage base area, 0.0409 ft^2 (0.003800 m^2)

$\frac{x_{cp}}{l}$ center-of-pressure location in fraction of body length, measured aft from nose

α angle of attack, deg

δ cant angle, measured from body axis, deg

ϕ roll angle of fins measured from vertical plane, deg

APPARATUS AND METHODS

Model and Support System

Details of the model are presented in figure 1. With the exception of the steel fins the model was constructed of aluminum alloy. The fourth stage had an ogive nose on a cylinder and was approximately 17 percent larger in diameter than the third stage. The fineness ratio of the model (third and fourth stages together) was about 17.4 based on the diameter of the third stage. Transition between the two stages was made by a boattail fairing. The model was provided with three sets of cruciform fins (fig. 1(b)). Two of these sets differed only in size; both had trapezoidal planforms and flat airfoils with wedge-shaped leading and trailing edges. The third set had an area equal to the larger of the trapezoidal fins, but had swept leading and trailing edges and a single-wedge airfoil section. The leading edges were rounded; the two large fin configurations had leading-edge radii of about 0.015 in. (0.0381 cm) and the small trapezoidal fins had a radius of about 0.010 in. (0.0254 cm). The three sets were attached to the body with the center of the root chords at the same longitudinal body station and were canted 1.1° with respect to the body center line to provide a positive rolling moment. In addition, the small trapezoidal fins were constructed to provide a cant angle of 0° and provision was made to roll the fins 45°. The geometry of the fin configurations is summarized in the following table:

Exposed fins, per plane (two fins)					
Planform	Section	A_e	Taper ratio	Span, ft (m)	Area, ft^2 (m^2)
Swept	Wedge	1.83	0.594	0.528 (0.1609)	0.152 (0.014121)
Trapezoidal	Flat	2.62	.425	.633 (.1929)	.153 (.014214)
Trapezoidal	Flat	2.26	.482	.502 (.1530)	.112 (.010405)

The model was attached to an internally mounted strain-gage balance which was attached to a rear-mounted sting. The sting, in turn, was attached to the tunnel central support system which allows remote control of the model attitude in the test section.

Tests and Corrections

Tests were made in the high Mach number test section of the Langley Unitary Plan wind tunnel through an angle-of-attack range from about -4° to 13°, at an angle of sideslip of 0°, and at Mach numbers of 2.30, 2.96, 3.96, and 4.63. The free-stream stagnation temperature was maintained at 150° F (339° K) for $M = 2.30$ and 2.96 and 175° F (353° K) for $M = 3.96$ and 4.63. A constant Reynolds number per foot (per 0.3048 m) of 3.0×10^6 was maintained for all Mach numbers. The stagnation dewpoint was maintained at -30° F (239° K) in order to avoid condensation effects. The results have been corrected for flow angularity and deflection of the balance and sting under load. The balance chamber pressure was measured and the axial force was adjusted to a base pressure equal to the free-stream pressure. The accuracies of the data are estimated to be:

C_N . . . . ± 0.0190
C_A . . . . ± 0.0017
C_m . . . . ± 0.0210
C_l . . . . ± 0.0050
α, deg . . . . ± 0.01
M (2.30 to 2.96) . . . . ± 0.015
M (3.96 to 4.63) . . . . ± 0.050

PRESENTATION OF RESULTS

The results of the investigation are presented in the following figures:

DISCUSSION

The longitudinal aerodynamic characteristics of the body alone and of the body with the small trapezoidal fins at cant angles of 0° and 1.1° are presented in figure 2. There appears to be little effect of fin cant on the pitch characteristics of the model in the test angle-of-attack and Mach number range. A comparison of the pitch data for the model with the various fin arrangements ($\delta = 1.1^{\circ}$) and with the small trapezoidal fins rolled 45° is shown in figure 3. The roll angle of the small trapezoidal fins has only a small effect on the pitch characteristics of the model. Both of the larger fin configurations provide increased normal force and stability as would be expected, although the swept fins provide the greater increase in stability. The increased effectiveness of the swept fins may be attributed to the difference in both planform and airfoil section. The primary effect of planform is the increased tail moment arm due to the leading- and trailing-edge sweep. Increased values of C_N (fig. 3) indicate increased fin lift which may be attributed at least in part to the single-wedge airfoil section which would be expected to have a larger lift-curve slope than the flat double-wedge airfoil of the trapezoidal fins. The axial force of the swept-fin configuration is greater than that for the trapezoidal-fin configuration, particularly at lower Mach numbers, and this increase is also an effect of the airfoil section which results in a blunt trailing edge for the swept fin.

The variations of the longitudinal stability parameters with Mach number (fig. 4) are about the same for the stability parameters of all the fin arrangements and differ only in absolute levels.

The roll characteristics of the model with the various fin configurations (figs. 5 and 6) show that the 1.1° cant angle leads to positive roll effectiveness throughout the test angle-of-attack and Mach number range and that the 45° attitude of the small trapezoidal fins has no appreciable effect on the model C_l (fig. 5). Except for the low angles of attack at $M = 2.30$, the roll effectiveness of the swept fins is greater than that of the large trapezoidal fins (fig. 6).

SUMMARY OF RESULTS

An investigation at Mach numbers from 2.30 to 4.63 to determine the aerodynamic characteristics of a 1/6-scale model of the Argo D-4 third- and fourth-stage configuration with several different cruciform fin configurations indicates the following results:

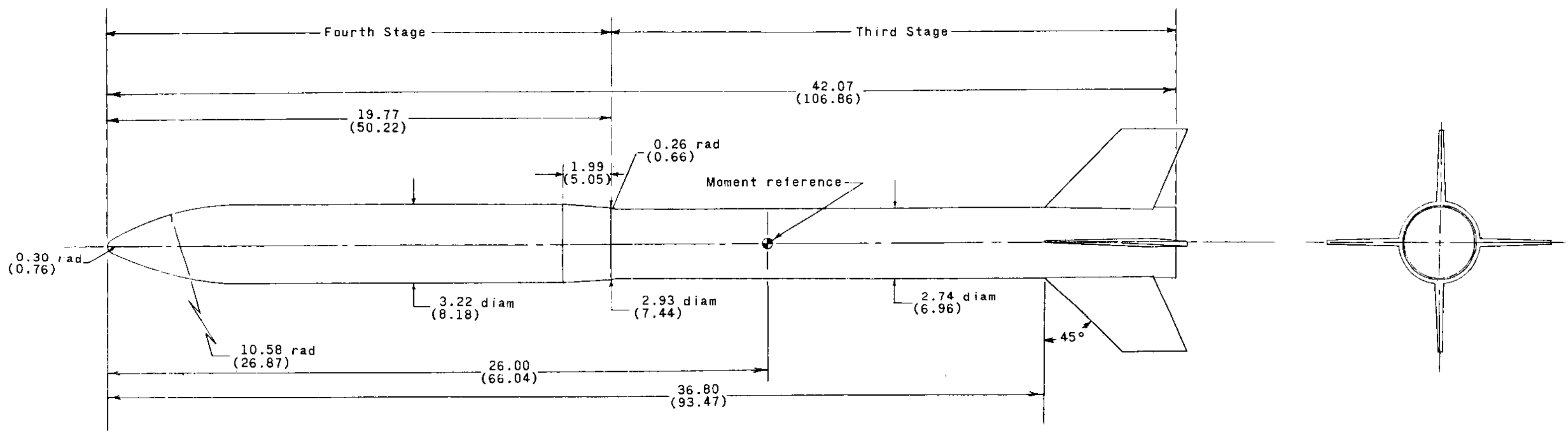
1. The swept-fin configuration provided greater longitudinal stability than the trapezoidal-fin configuration of equal area, because of a greater effective moment arm and the increased lift-curve slope of the single-wedge airfoil of the swept-fin configuration.

2. The swept-fin configuration generally provided a greater rolling moment than the trapezoidal-fin configuration of equal area.

3. There was no appreciable effect of fin roll attitude on either longitudinal stability or rolling moment.

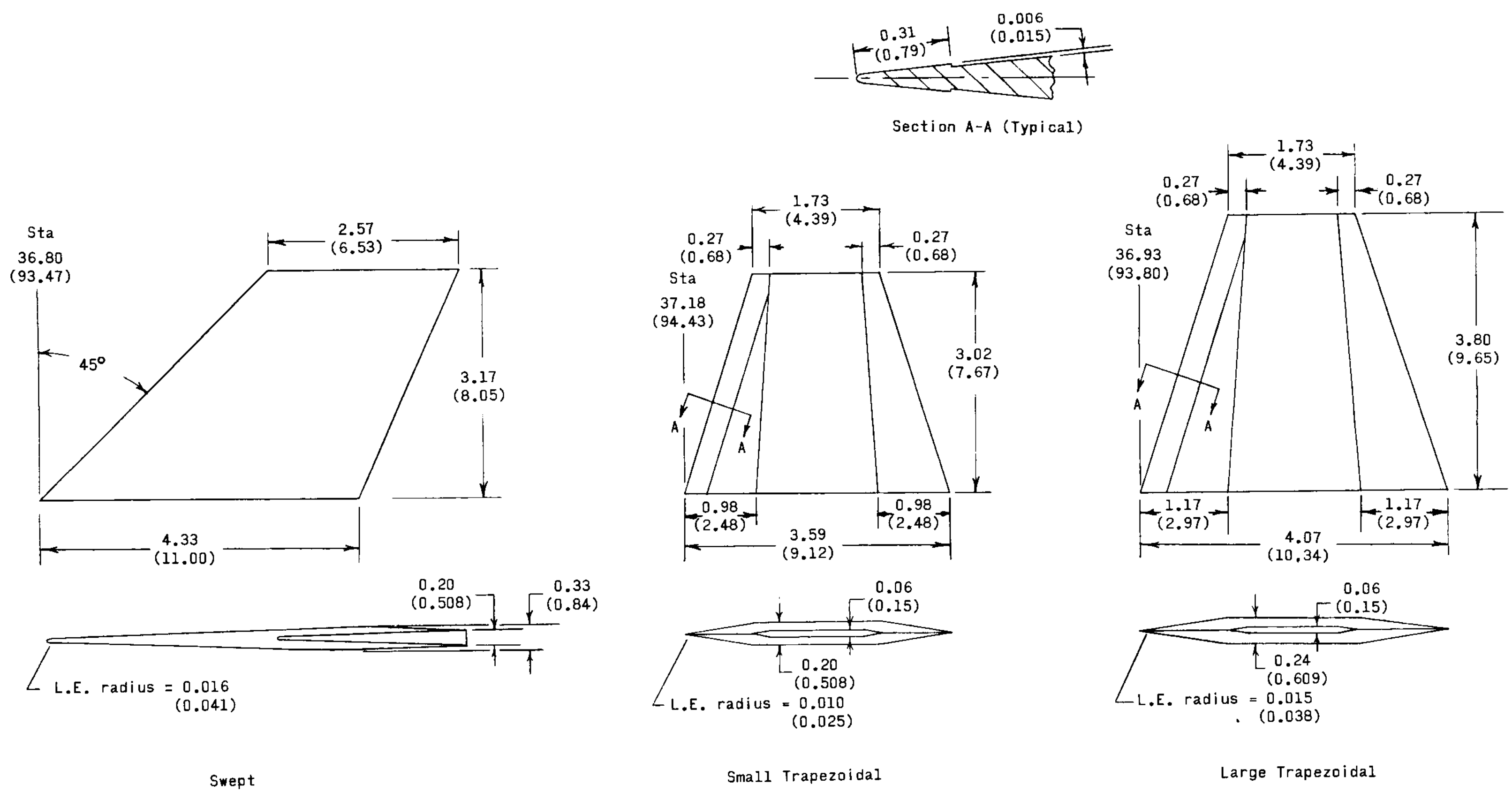
4. A fin cant of 1.1° to provide rolling moment had no effect on longitudinal stability.

Langley Research Center,
National Aeronautics and Space Administration,
Langley Station, Hampton, Va., June 25, 1965.



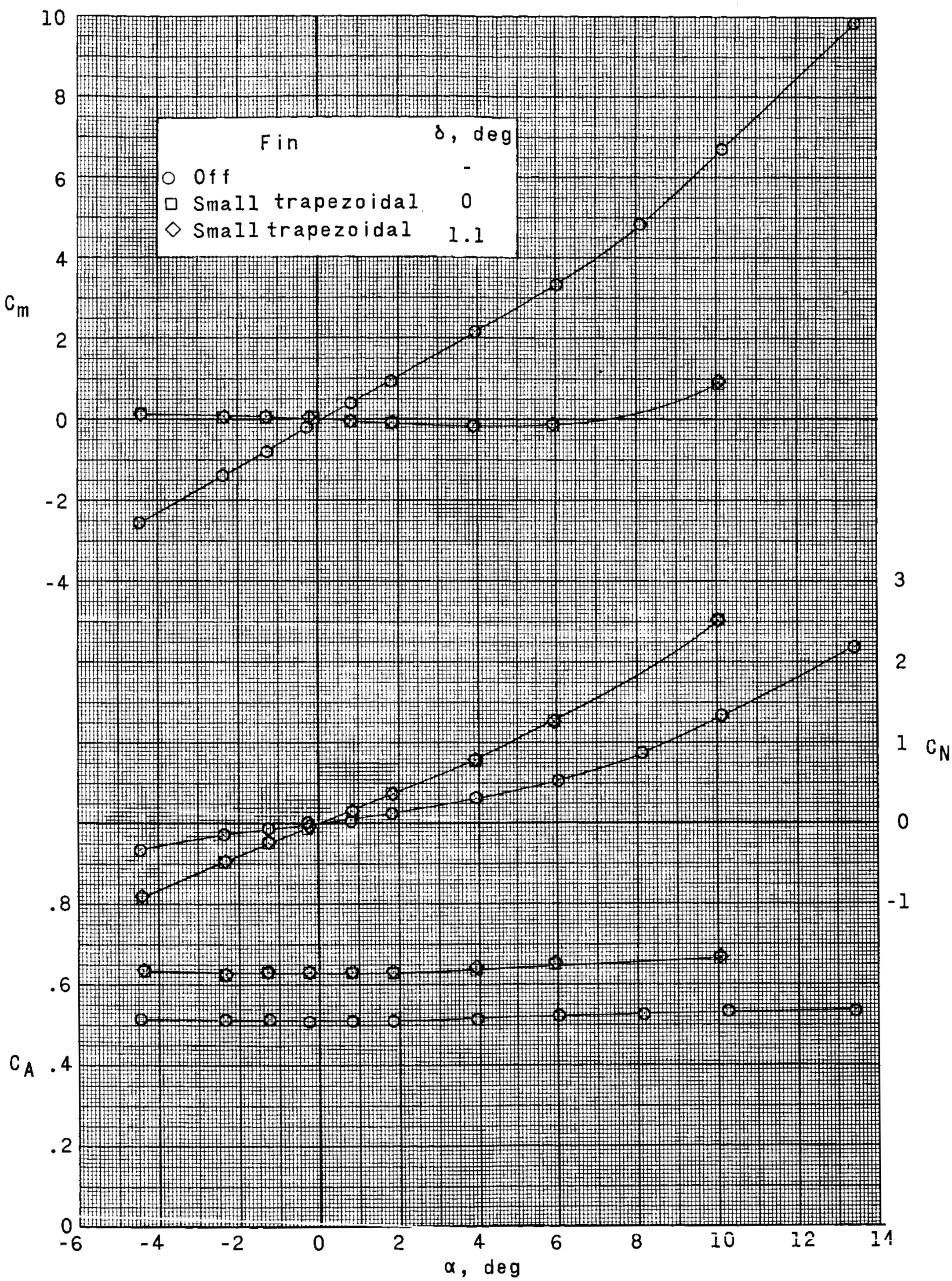
(a) Body details.

Figure 1.- Details of the model. All dimensions are in inches (centimeters) unless otherwise indicated.



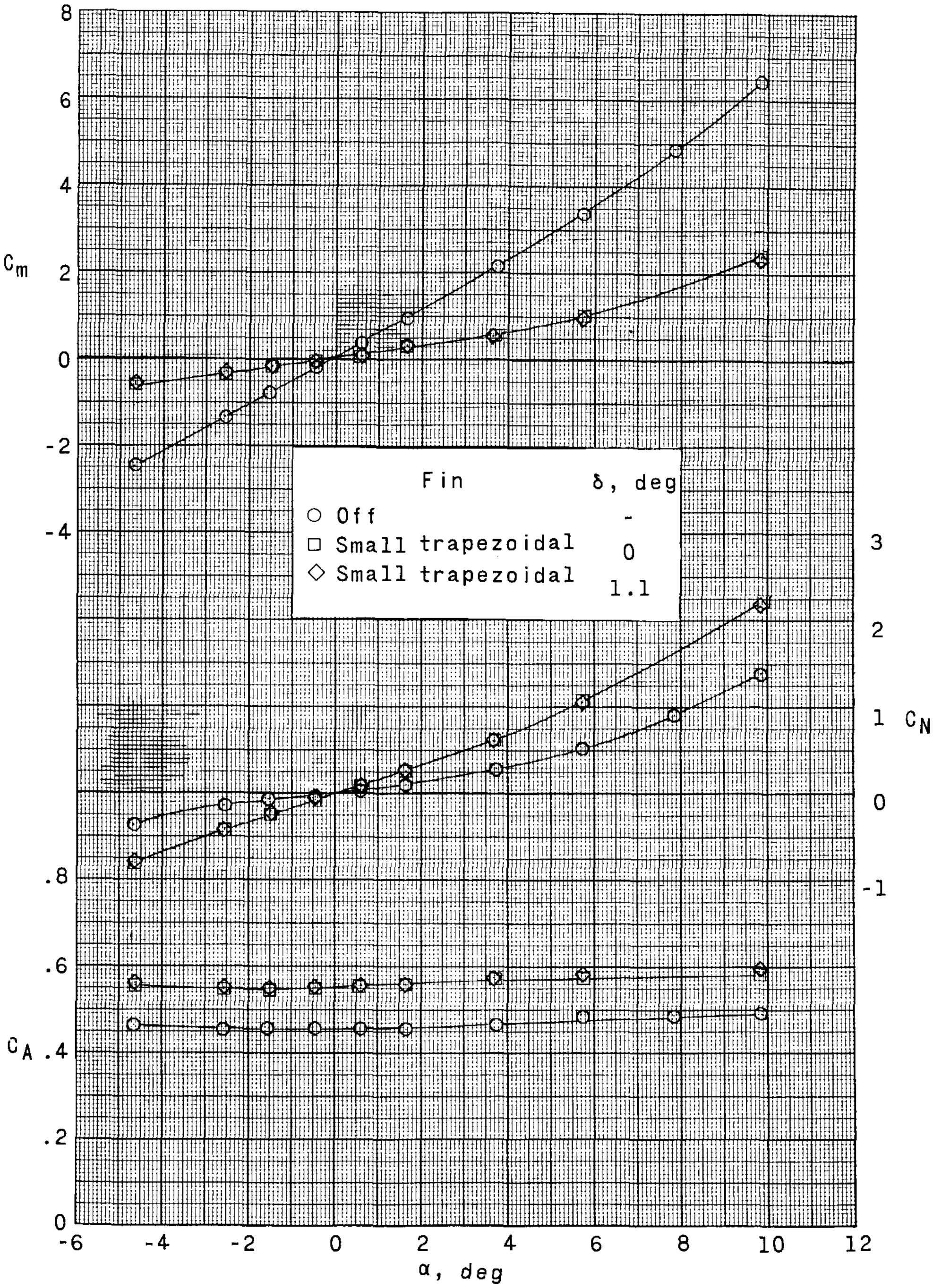
(b) Exposed fin details.

Figure I.- Concluded.



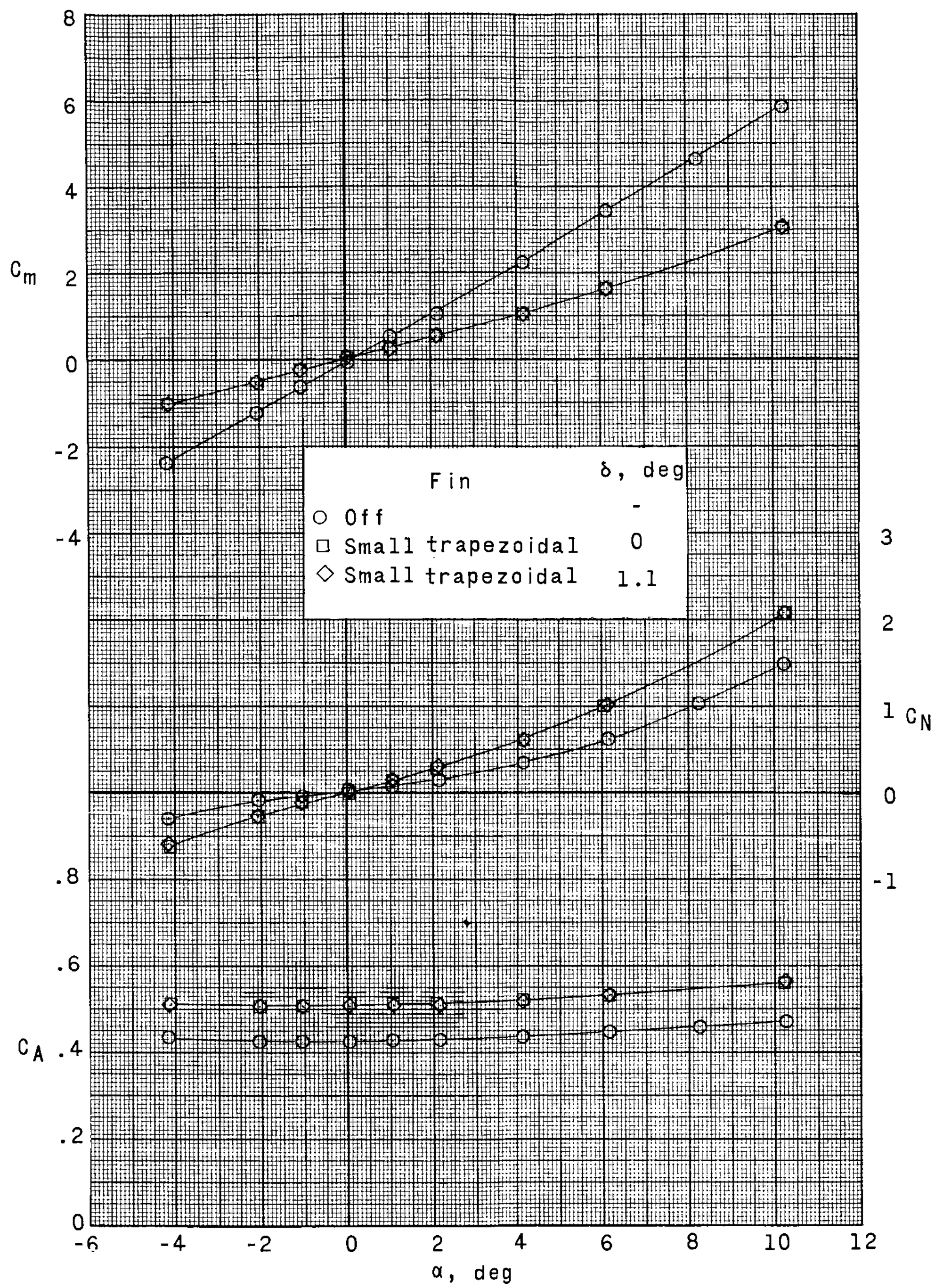
(a) M = 2.30.

Figure 2.- Effect of small trapezoidal fins and fin cant on longitudinal aerodynamic characteristics. $\phi = 0^{0}$.



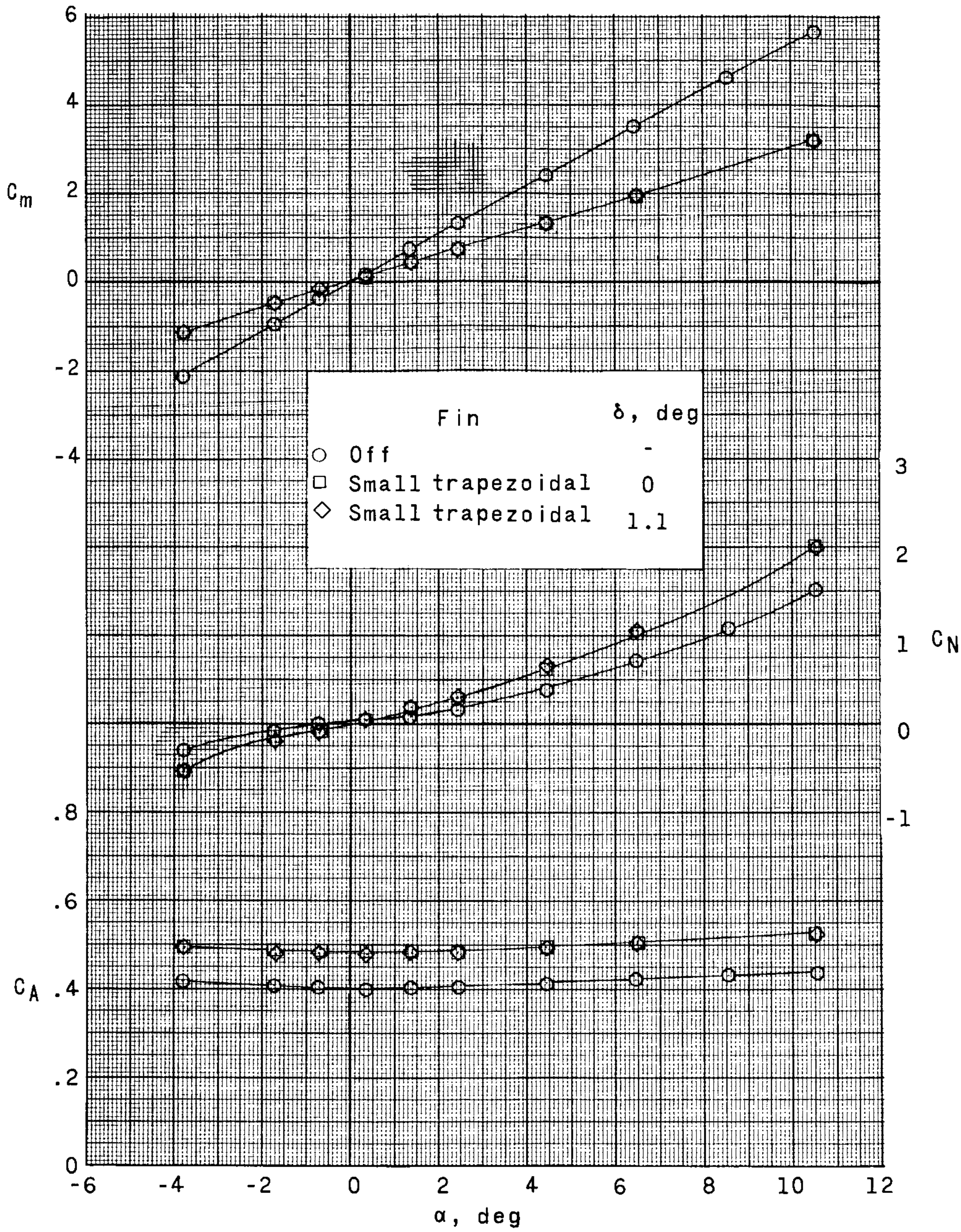
(b) M = 2.96.

Figure 2.- Continued.



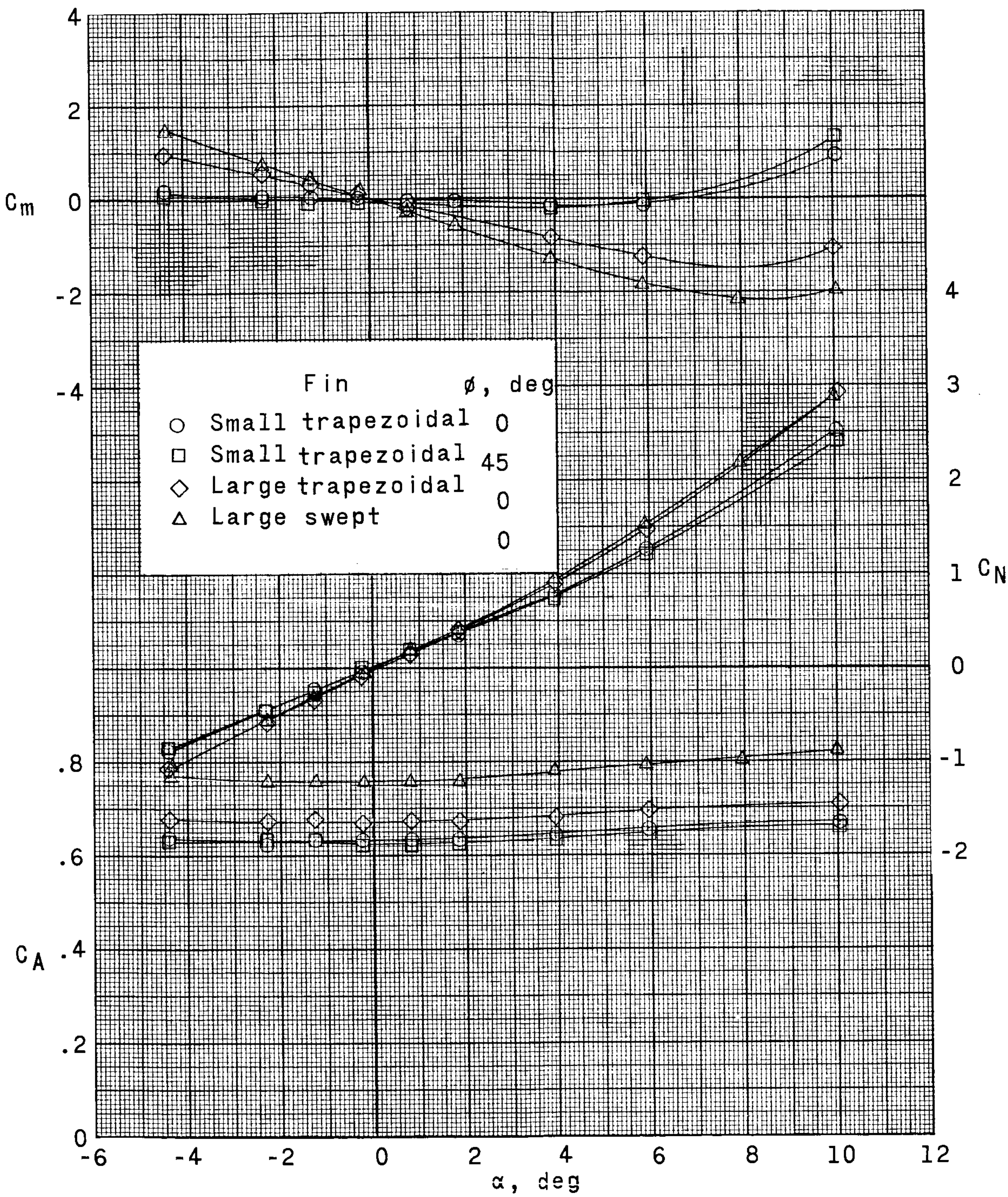
(c) M = 3.96.

Figure 2.- Continued.



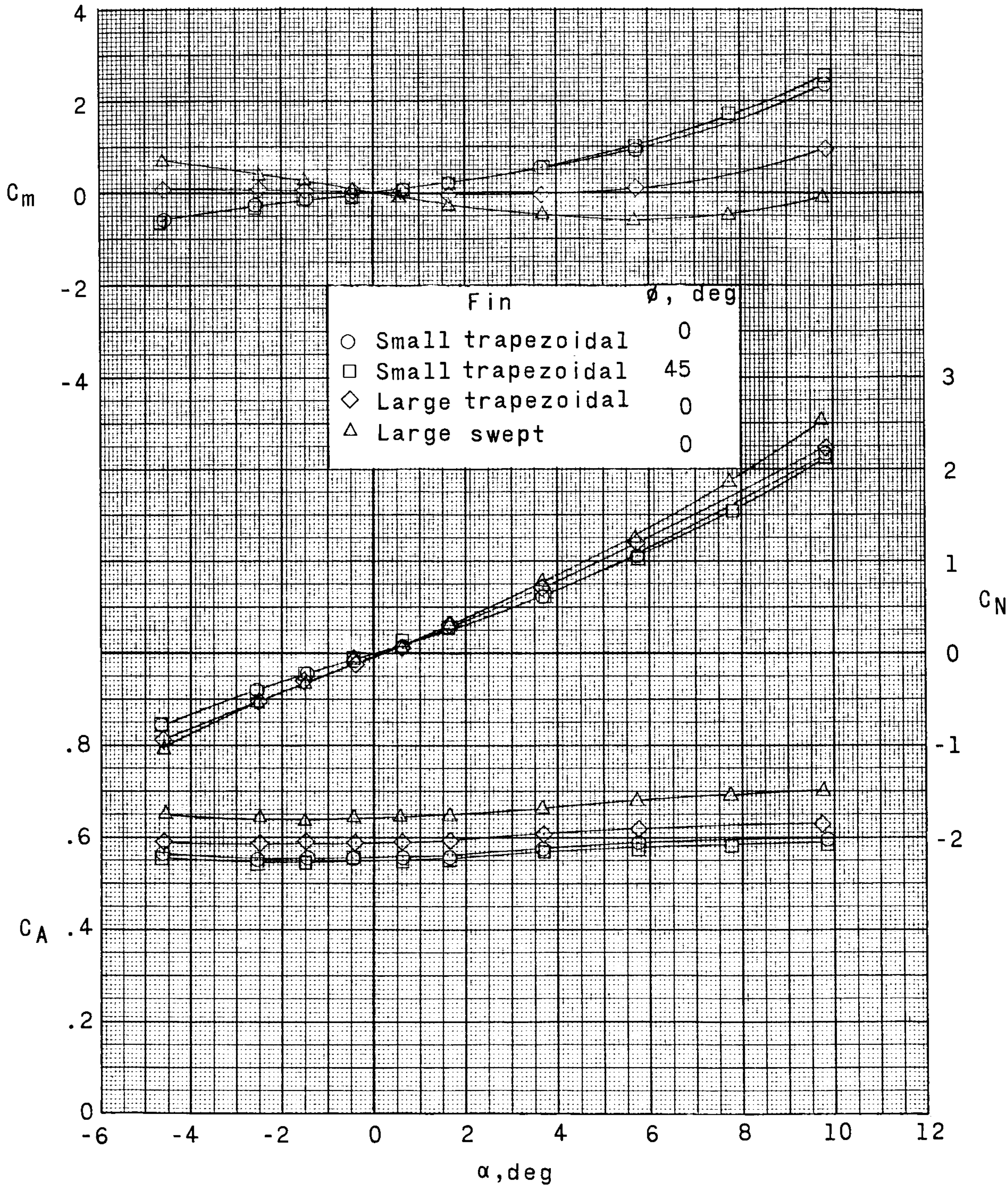
(d) M = 4.63.

Figure 2.- Concluded.



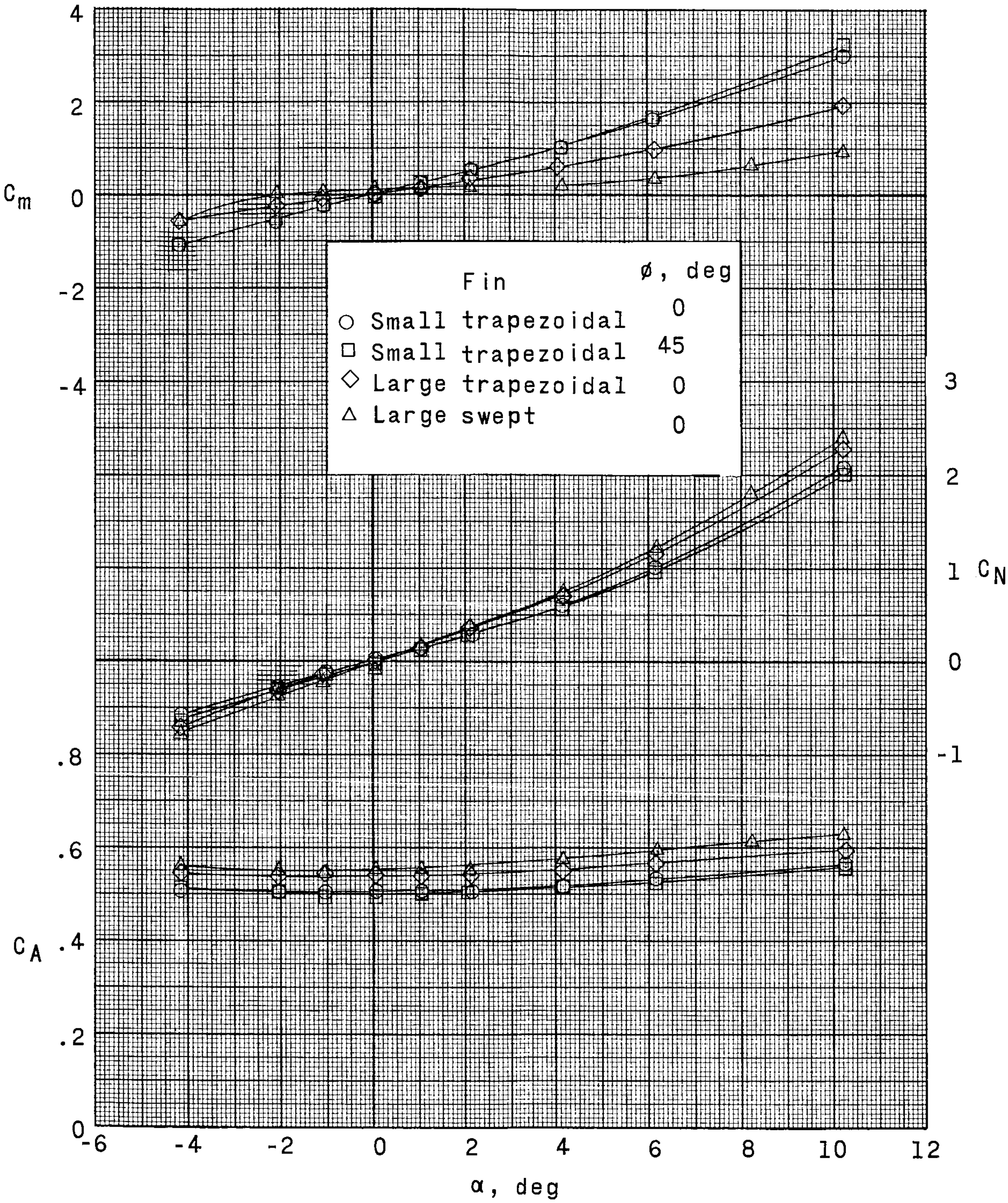
(a) M = 2.30.

Figure 3.- Effect of fin size, planform, and roll angle on pitch characteristics. δ = 1.1°.



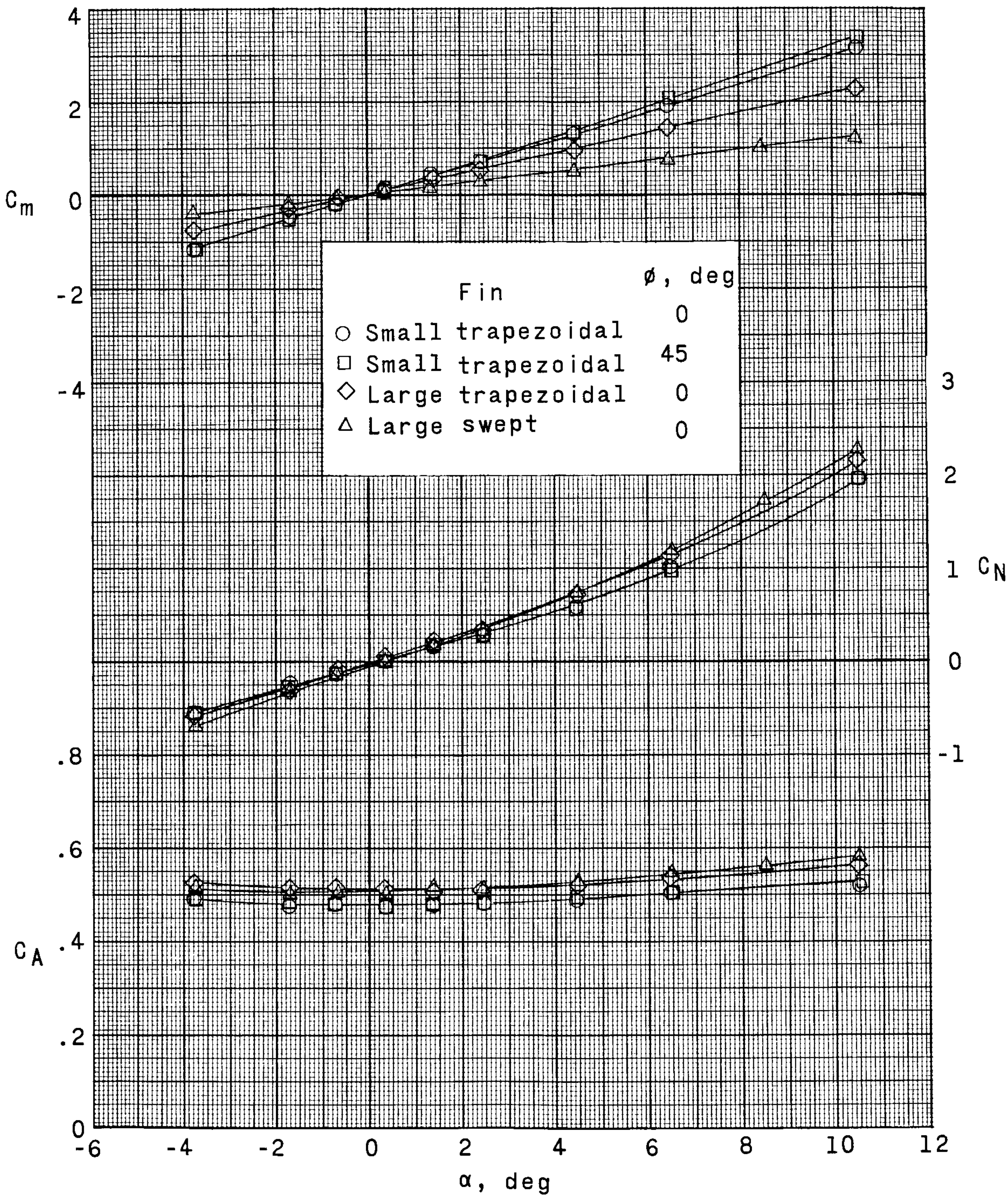
(b) M = 2.96.

Figure 3.- Continued.



(c) M = 3.96.

Figure 3.- Continued.



(d) M = 4.63.

Figure 3.- Concluded.

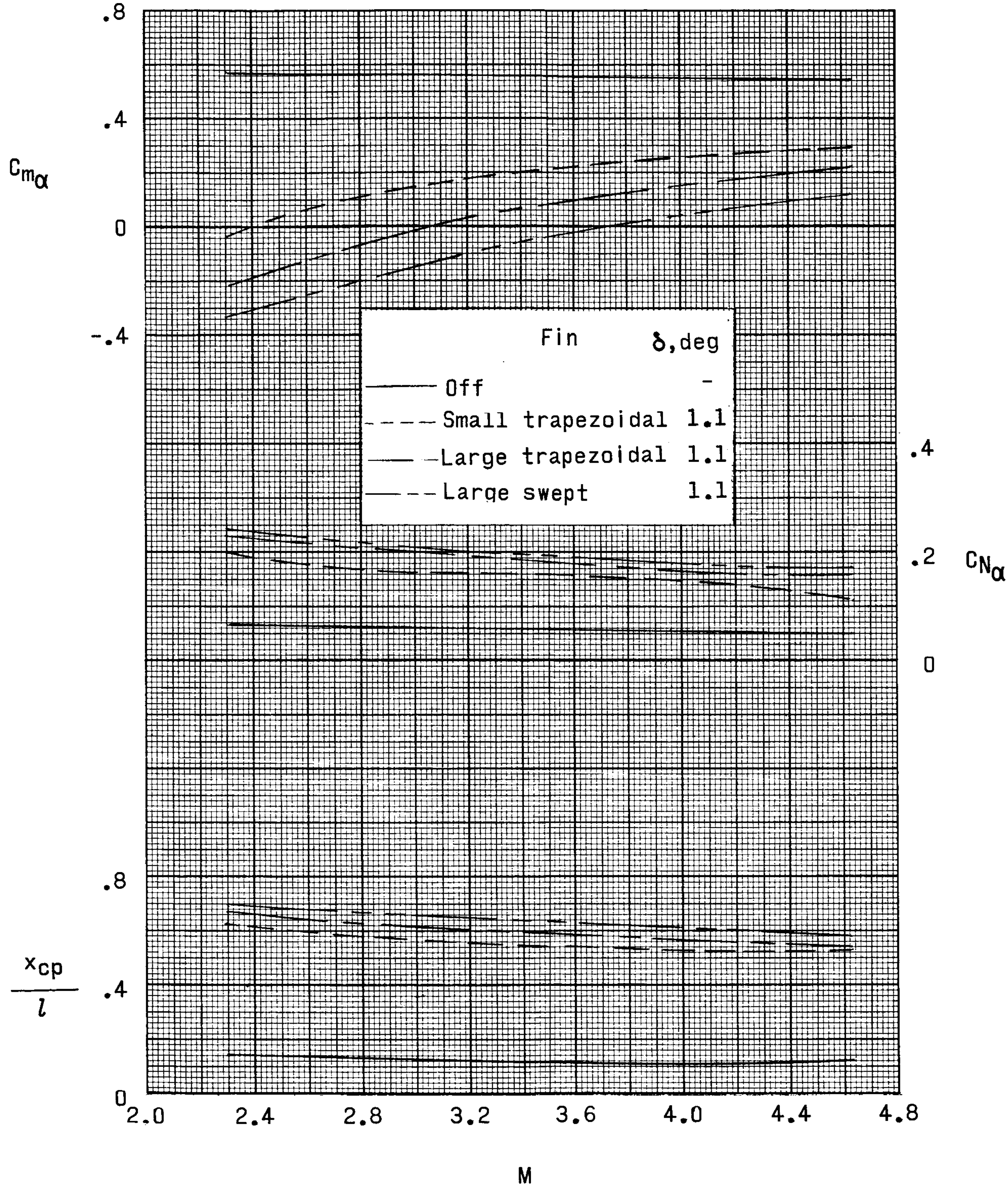


Figure 4.- Variation of longitudinal stability parameters with Mach number.

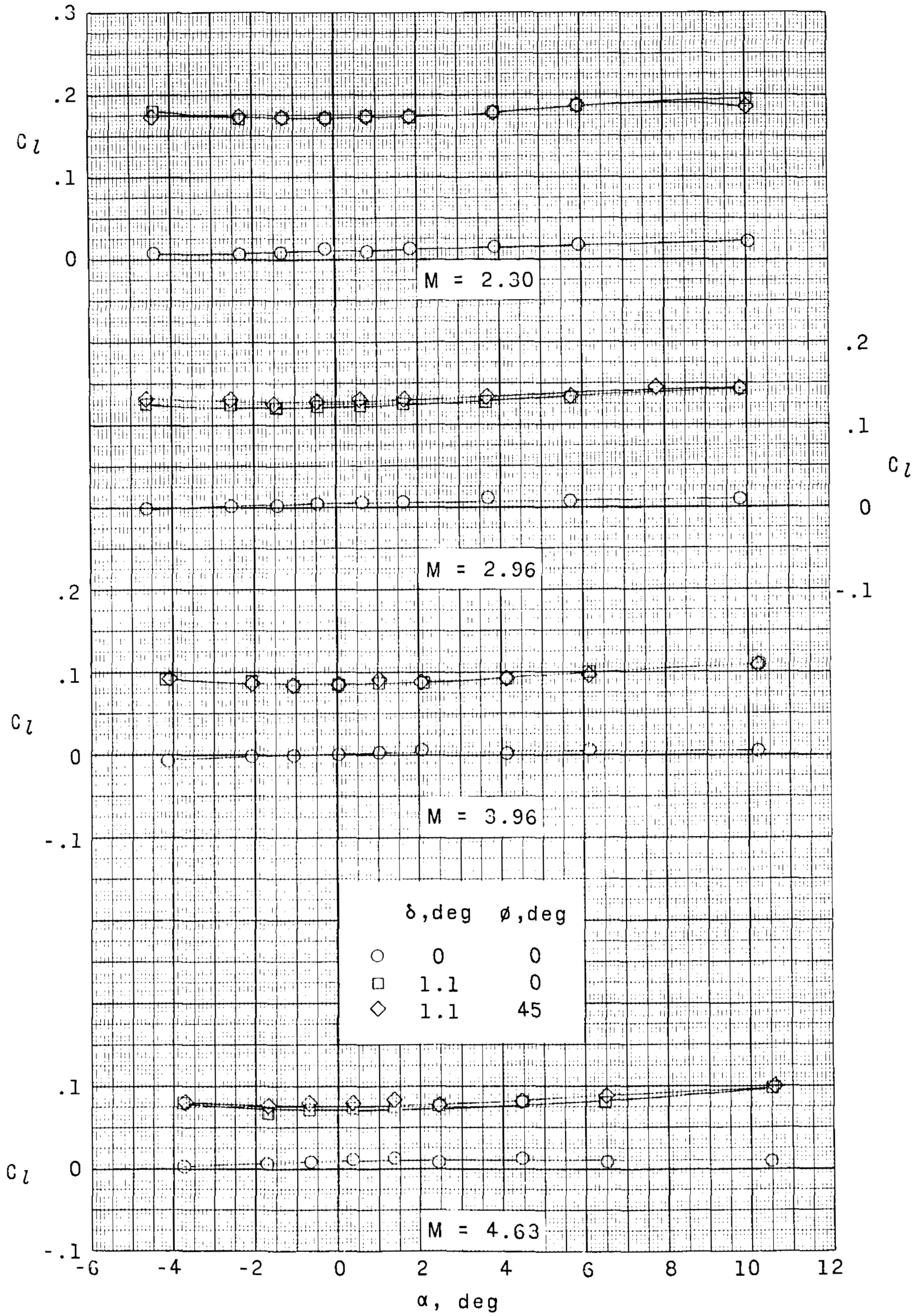


Figure 5.- Roll characteristics of the model with small trapezoidal fins.

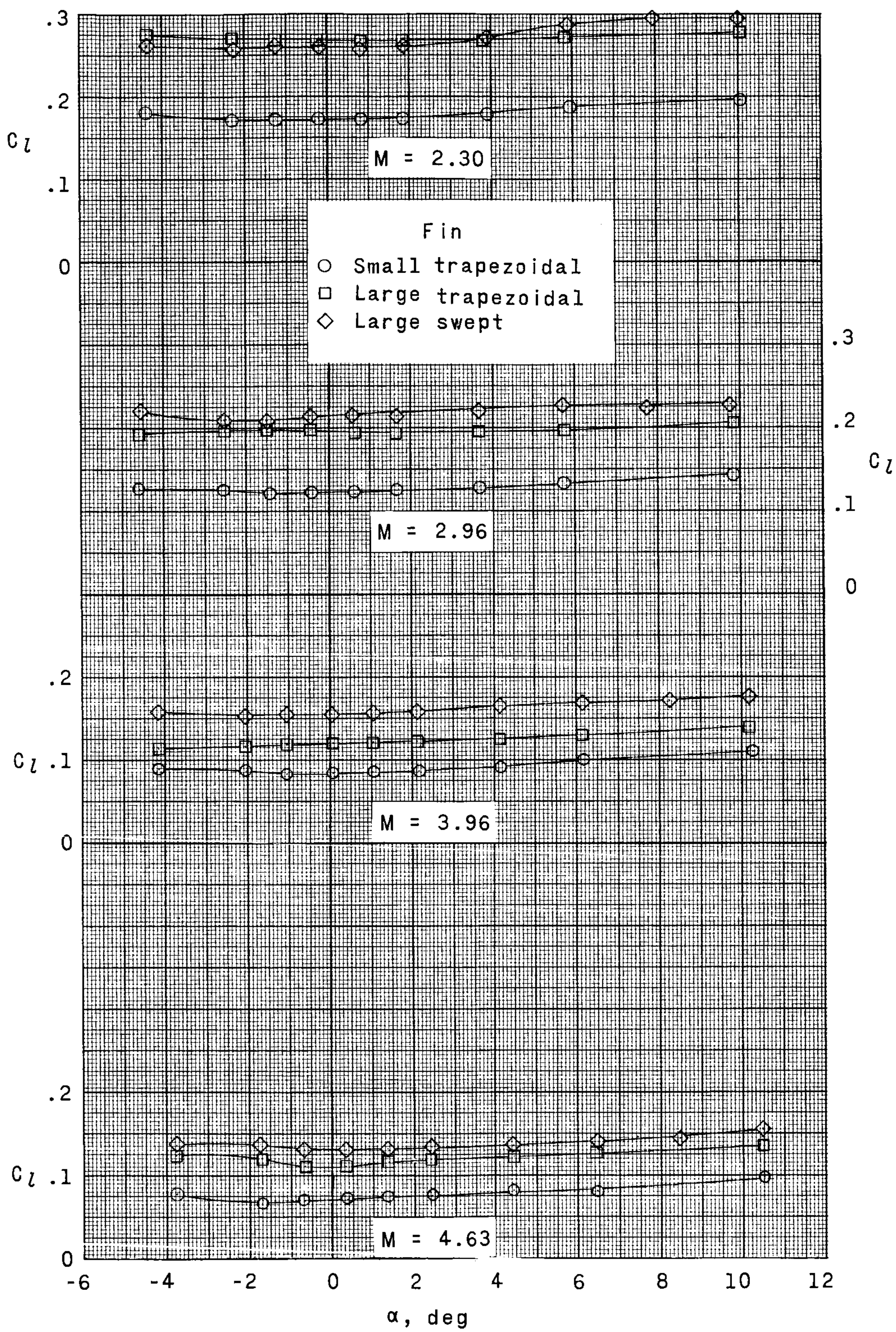


Figure 6.- Comparison of rolling-moment characteristics of model with various fin arrangements. δ = 1.1°; ϕ = 0°.